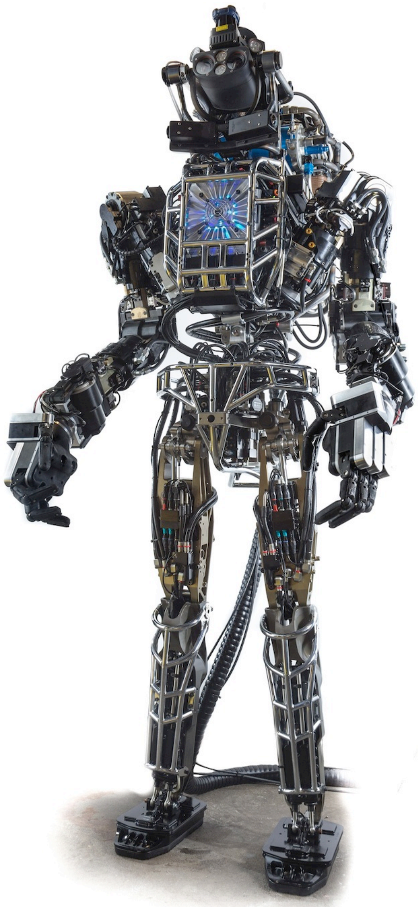


Manipulation is just walking (upside-down)

Russ Tedrake

russt@mit.edu
groups.csail.mit.edu/locomotion

Massachusetts Institute of Technology
MIT EECS
AEROASTRO
CSAIL

Problem formulation

- You have an object (possibly your robot) in an initial configuration.
- You want it in a different configuration.

- If you're a planning person:

  Find a feasible finite-time path from the initial configuration to the final configuration.

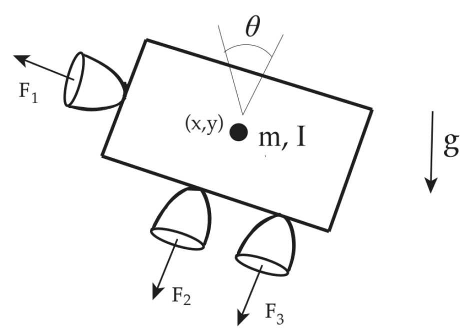
- If you're a control person:

  The distance between the current state and the desired state should go to zero as time goes to infinity.

- Respect *kinematic* and *dynamic* constraints.

Problem formulation (cont)

Start with a single rigid body. Call it a satellite:



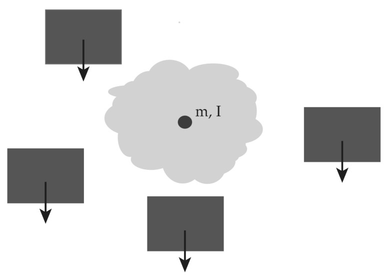
- Control Input: Thrusters (exert force on the world)
- Constraints: force limits (e.g. push not pull), avoid obstacles, ...

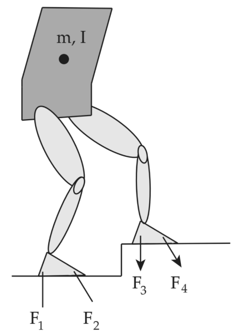
Now A Twist: Only two thrusters, but can move thrusters relative to body.
A Catch: No thrust while thruster moves. Moving costs time and energy.

The Legged Locomotion Problem

Let's add more constraints:

- Can only produce force when they are in certain locations. (e.g. at the terrain)





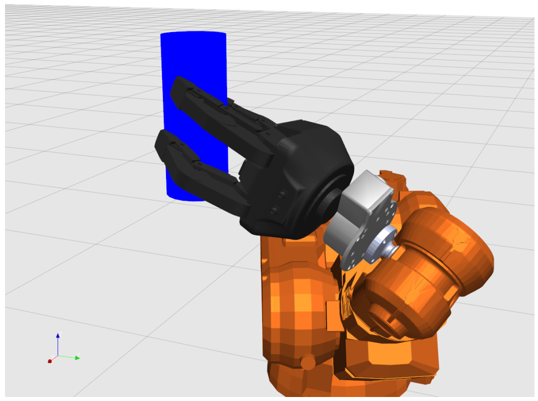
- Kinematic constraints of the "leg", friction cones, ...

This is the fundamental problem for legged locomotion:
Where/when do you put your thrusters, and how hard do you push?

A dynamics component. A geometric component. A scheduling component.

The Manipulation Problem

Ok. Basically the same problem...

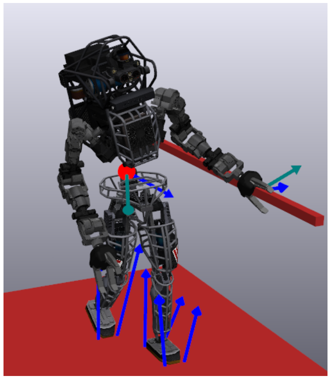


Where/when do you put your fingers, and how hard do you push?

Similar geometric constraints (object geometry; arm/hand kinematics), same force constraints.

Some important differences...

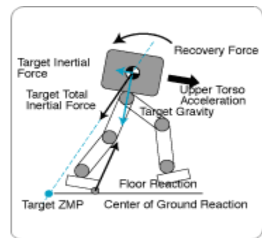
Difference #1: Dynamic stability



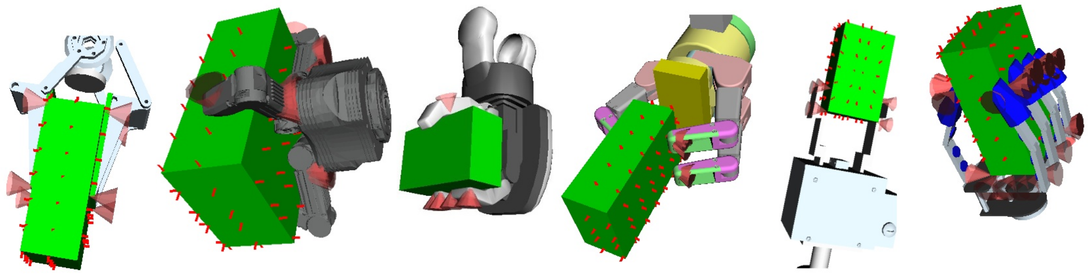
In locomotion:

- Contact constraints are almost beneath the robot, and unilateral (reaction forces only point up)
- Requires balance. Emphasis on stability and control.

- Also enabling:
  - All contacts forces in a plane can be summarized by a single zero-moment point
  - Planning simple dynamically stable gaits becomes a linear optimal control problem



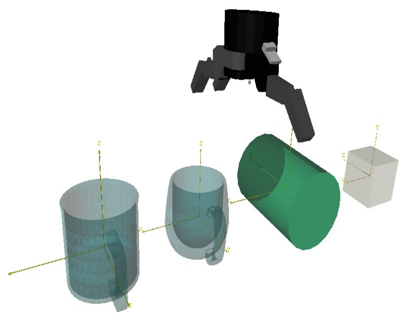
Difference #1: Dynamic stability (cont)



- In manipulation:
  - Often get to surround the object w/ contacts
  - Emphasis on statics: force closure, grasp quality
  - More work on generic contact modeling (LCP, ...)
- In walking:
  - More emphasis on collision/impact (can be destablizing; or stabilizing)
  - Periodic (limit-cycle) stability
  - Often assume flat terrain, but we're getting better!

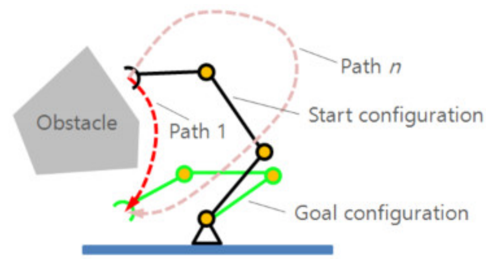
Difference #2: Uncertainty

- In manipulation:
  - More uncertainty about contact positions/constraints
  - Don't know object geometry, inertia, friction, ...
  - Emphasis on grasp quality (static robustness) and **motion planning under uncertainty**
  - I'm surprised there is not more work in system-theoretic robustness analysis



(Historical) Difference #3: Planning emphasis

- In manipulation:
  - More emphasis on collision-free kinematic planning
- In locomotion:
  - More emphasis on dynamic planning
  - With collisions, but simple geometry

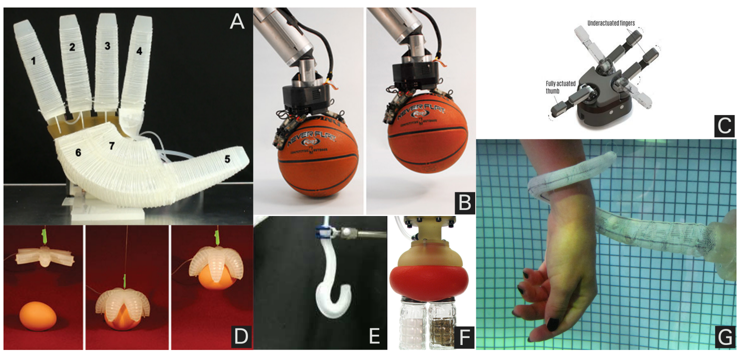


(Historical) Difference #4: Integrating perception

- More emphasis on perception in manipulation; but some recent work in locomotion
- Includes vision, depth-cameras, but also contact sensors (skin, etc)

Underactuated mechanisms

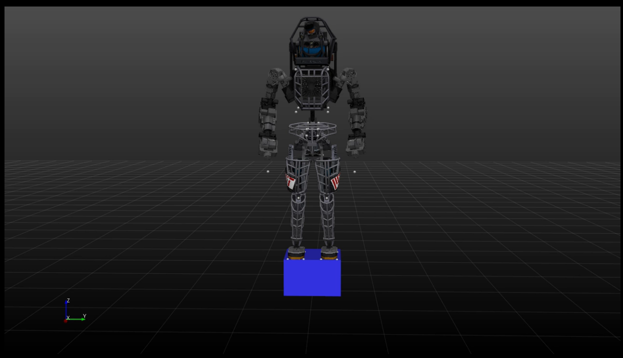
- Passive walking: physics makes control easier (MAYBE)

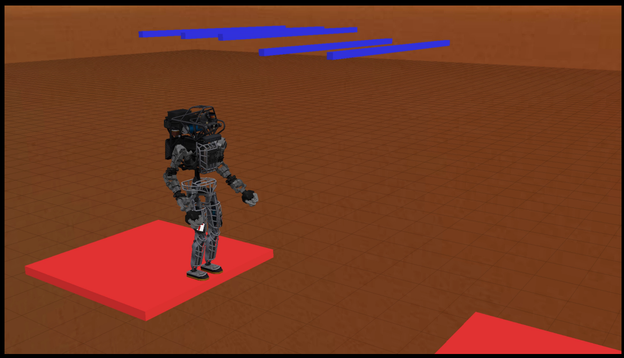


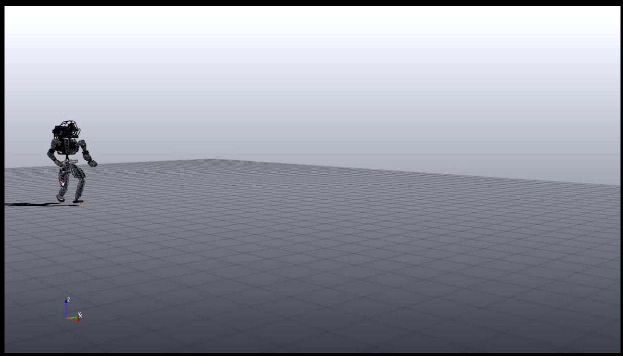
- Underactuated hands to cope with geometric uncertainty
- Surprised we haven't seen more work in manipulation planning w/ dynamics

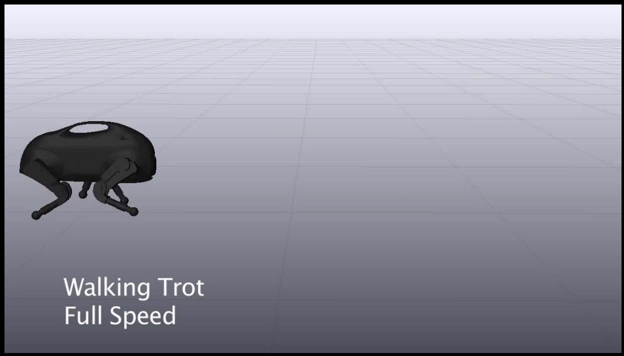
Really the same problem...

Generalized approach: planning (through contact)

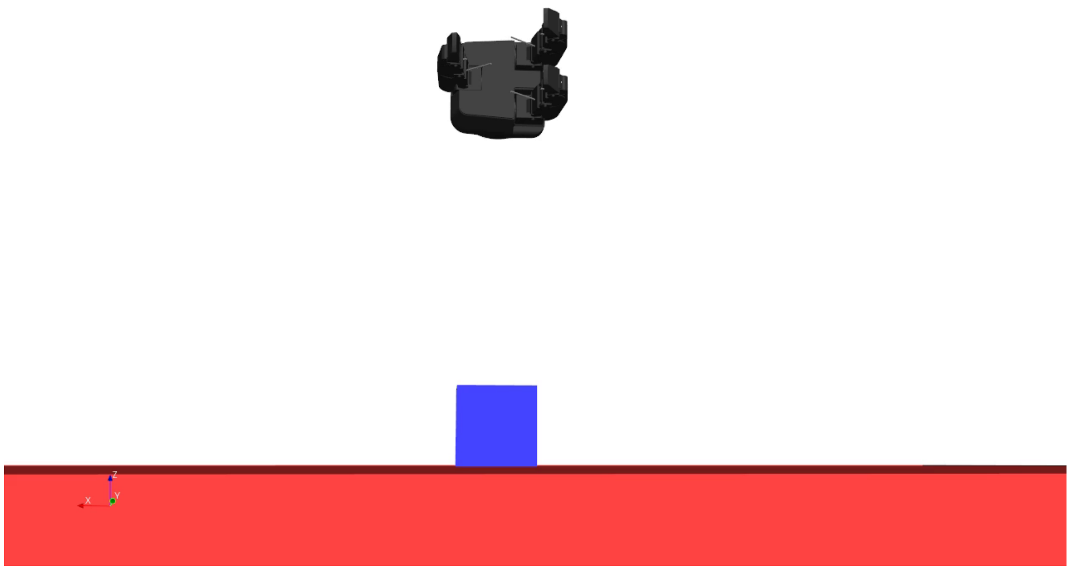








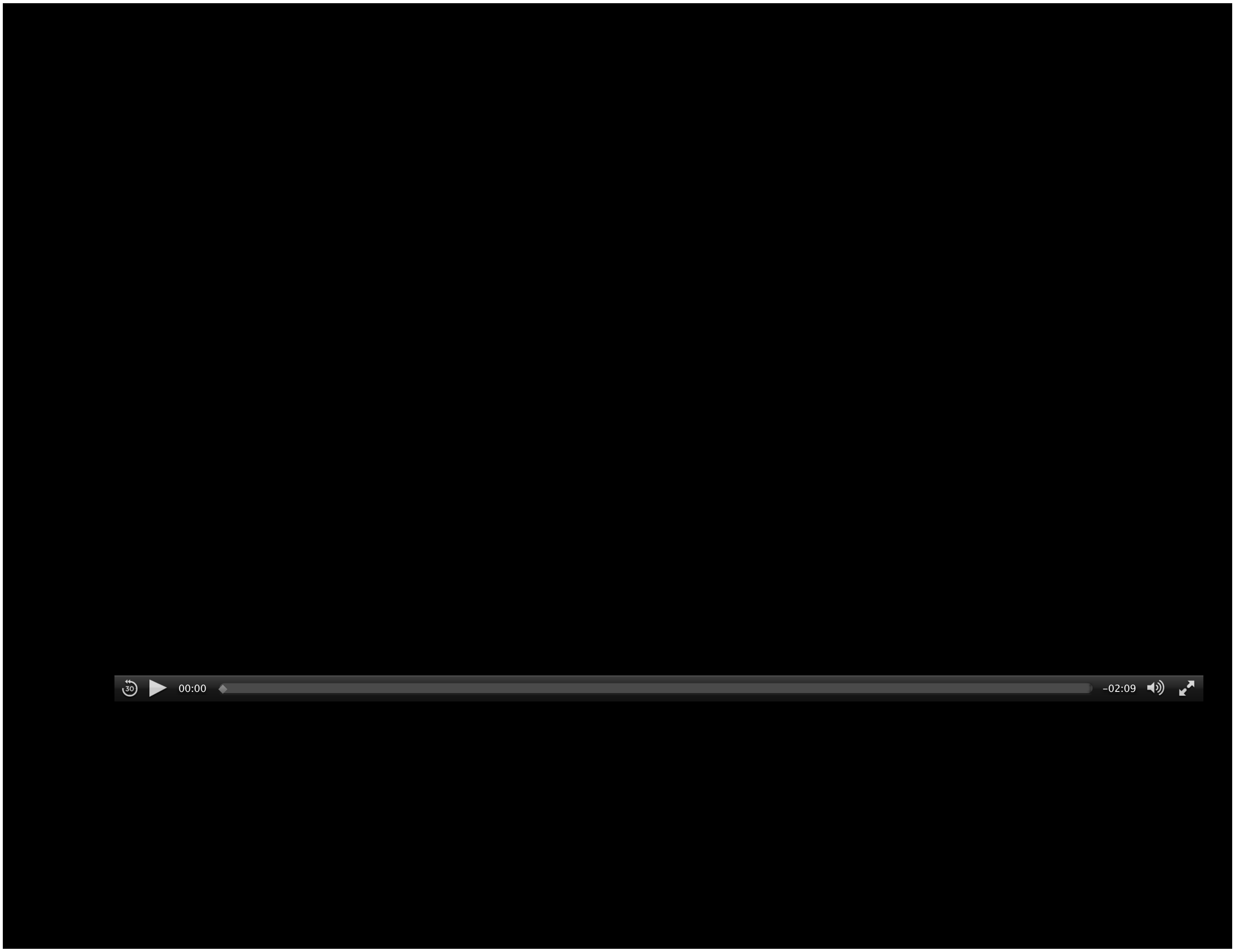
Generalized approach: planning (through contact)



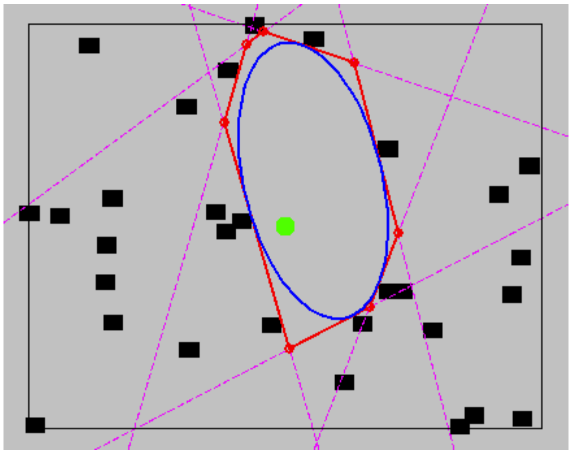
But these are still hard (nonlinear, nonconvex) optimizations.

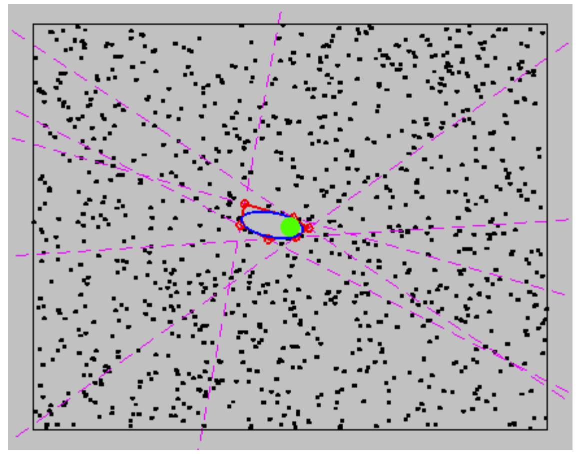
- Deep learning?
- I want to exploit more structure...

Exposing the combinatorial structure

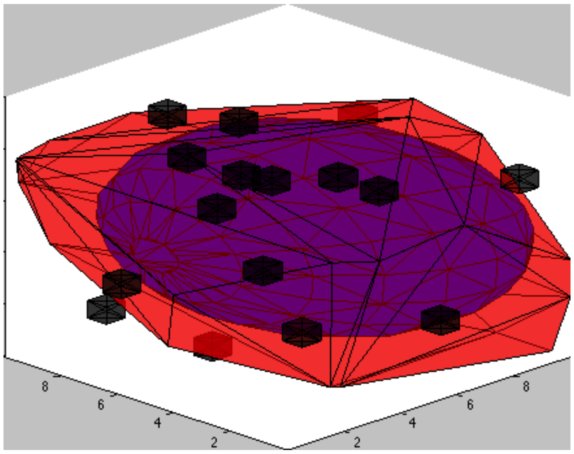

00:00
-02:09

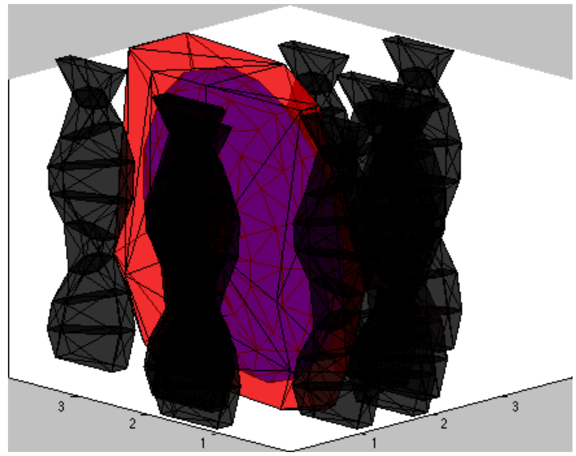
Super-fast approximate convex segmentation



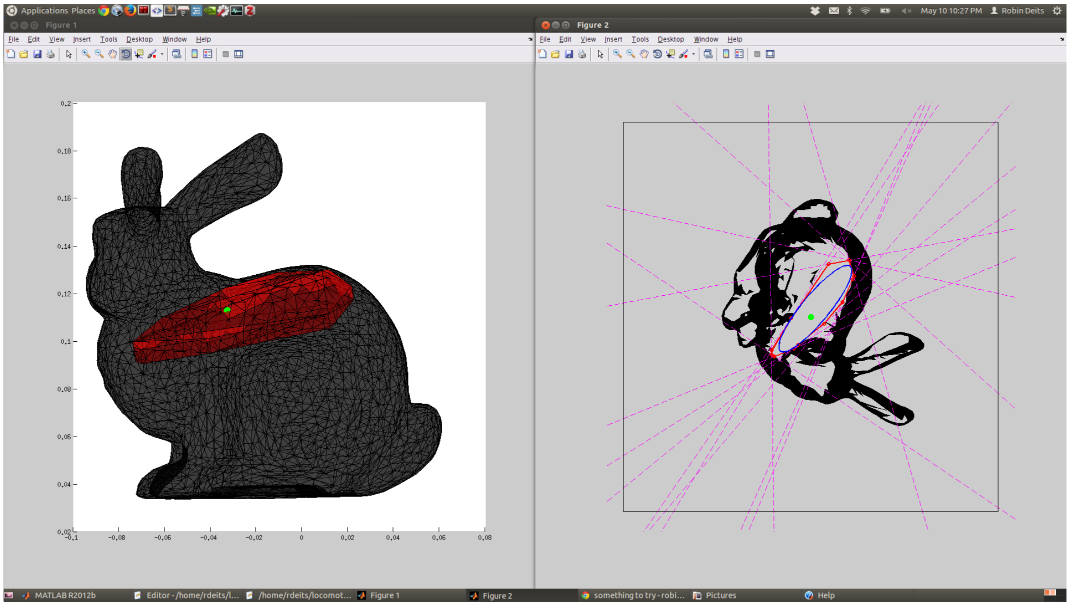


Super-fast approximate convex segmentation



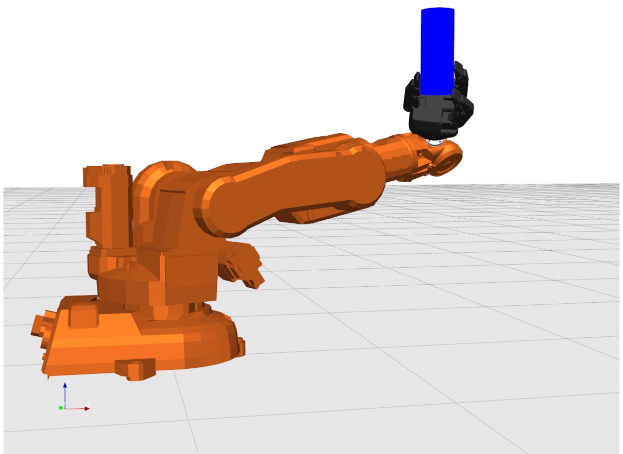


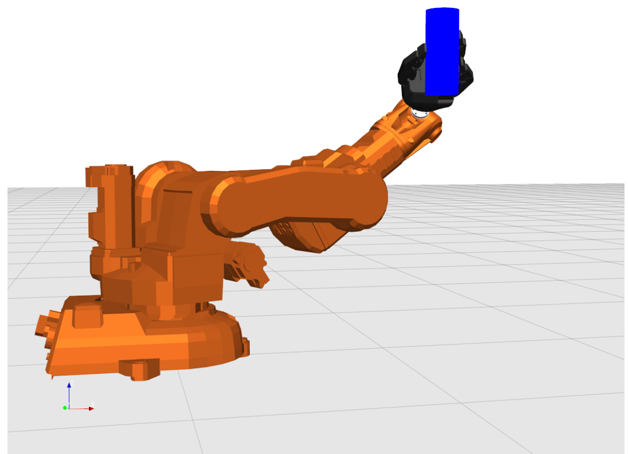
Works for manipulation, too



New work on combinatorial grasp optimization

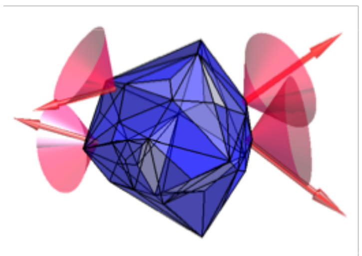
- Optimize forces *and* contact positions
- Bilinear Matrix Inequalities (solved as SDP w/ rank-minimization)

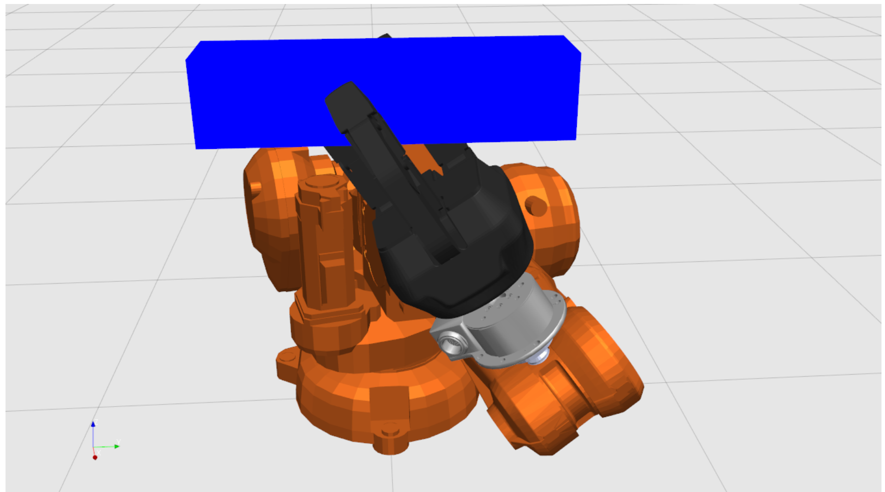




New work on combinatorial grasp optimization

- Optimize forces *and* **contact positions** for robustness
- Bilinear Matrix Inequalities (solved as SDP w/ rank-minimization)

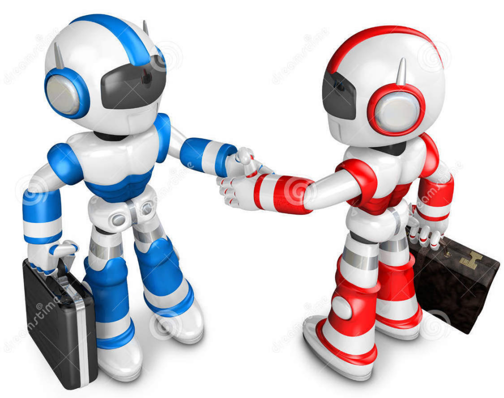




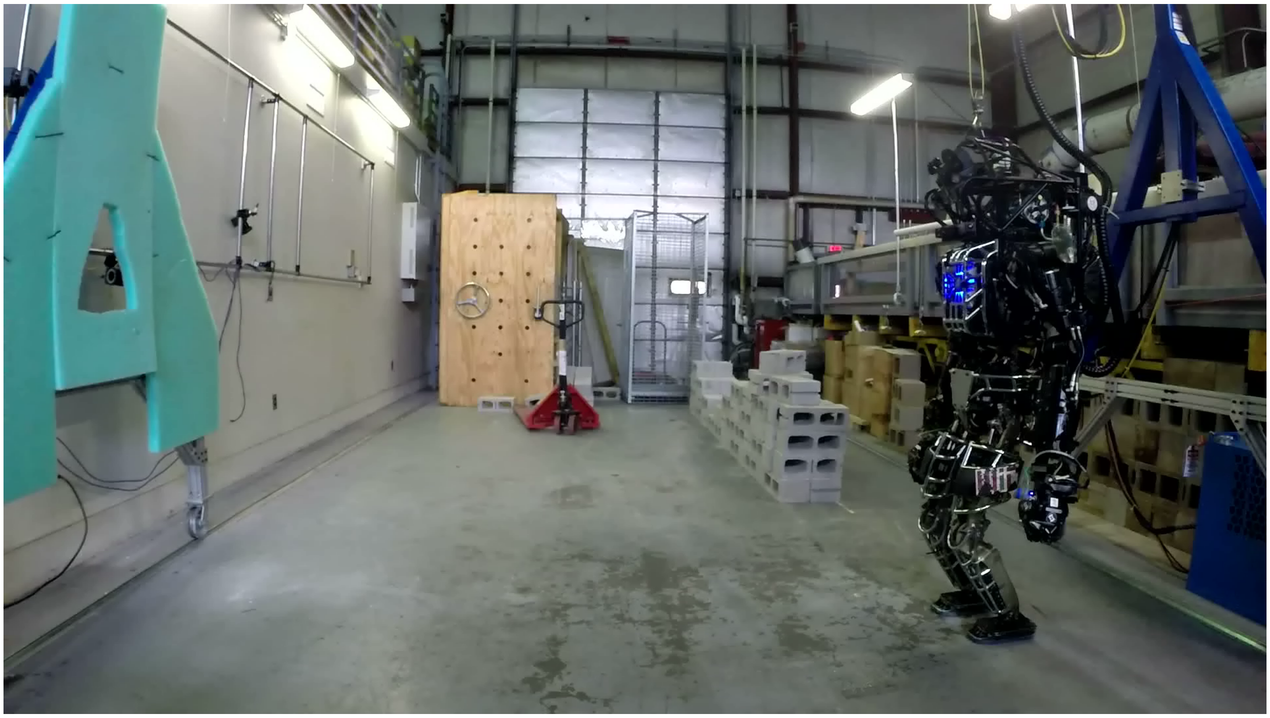
Working on soft robot manipulation

Summary

- What can manipulation learn from locomotion?
  - Dynamics and control viewpoint
    - e.g. for planning/control of underactuated hands
    - control formulations of robustness analysis (model-informed does not imply model-dependent)
- What can locomotion learn from manipulation?
  - ... ?
  - Interaction w/ perception
  - Collision-free motion planning
  - Planning under uncertainty



Fast(er) Atlas walking. [for Chris]



circa Oct, 2014